

A Semantics-based Communication System for Dysphasic Subjects*

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Abstract. Dysphasic subjects do not have complete linguistic abilities and only produce a weakly structured, topicalized language. They are offered artificial symbolic languages to help them communicate in a way more adapted to their linguistic abilities. After a structural analysis of a corpus of utterances from children with cerebral palsy, we define a semantic lexicon for such a symbolic language. We use it as the basis of a semantic analysis process able to retrieve an interpretation of the utterances. This semantic analyser is currently used in an application designed to convert iconic languages into natural language; it might find other uses in the field of language rehabilitation.

1 Introduction

The field of Assisted Communication for speech impaired people now offers a wide range of material or logical devices that produce audible sentences for the user. Few systems, though, provide a good communication for subjects whose language abilities, and not only speech ones, are impaired.

We have tried to tackle the problem of understanding asyntactic utterances produced by speech and language impaired people through a technique of semantic analysis. This principle has been implemented in a computer application, PVI (*Prothèse Vocale Intelligente*), allowing users to communicate through sequences of icons translated into French sentences. The same principle had already inspired the COMPANSION system [3], which converts, with different AI techniques, sequences of uninflected words into English sentences.

In this paper, we will expose in a first part what are the language disabilities we have to cope with, situate them in the frame of language disorders, and see what type of discourse disorganization they produce by examining a corpus.

In a second part, we propose a specific technique of semantic analysis able to analyse this type of discourse. We make some hypotheses on the structure of the language, draw a model able to represent it, and then expose the operations one can perform on this model.

* This work has taken place in the frame of the PVI (*Prothèse Vocale Intelligente*) project, funded by AGEFIPH and Thomson-CSF. It has involved constant cooperation of the Rehabilitation Centre of Kerpape (Lorient, Brittany, France).

We briefly describe the application in which the technique has been implemented. The application itself is described in more detail in [9].

We finally give some elements of evaluation of the system, as they emerge both from quantitative (benchmarking) and qualitative (on-site) evaluation.

2 Consequences of Dysphasia on the Language

2.1 Context of our Study

Speech and language disorders among children can be so miscellaneous in their nature as a simple language acquisition delay or a severe and permanent language deficit.

1. Language acquisition delay may be correlated with some types of mental retardation, or in some cases with social or psychological troubles. Children in this case present some symptoms like lack of phonological or syntactical control, appearing mainly though as mistakes of the same nature as typical childhood language mistakes — not as a systematic deviant linguistic behaviour.
2. A permanent language deficit may be a consequence of:
 - (a) a general developmental trouble like *autism*;
 - (b) a cerebral lesion acquired during childhood — in this case the language disorder is referred to as *acquired aphasia*;
 - (c) a specific language development disorder: *dysphasia*.

The subjects we are working with, children with cerebral palsy, suffer from a global language deficit due to stable cerebral lesions, consequence of a pre- or perinatal accident (e.g. prolonged anoxia).

It has been shown [4] that these children present language disorders which are very close to those of developmental dysphasia. In a clinical perspective, the diagnostic methods are the same, and the rehabilitation guidelines are the same in respect to the proper linguistic troubles. That is why we will further use the term of dysphasia as a set of clinical symptoms, which can be used to characterize the subjects in our study.

The techniques described in this paper have been implemented in communication help software for these children. We will present the types of speech and language troubles observed among the subjects, as these troubles may externally appear.

2.2 Nature of the Language Troubles

The subjects present various symptoms of speech disability, that may be classified roughly into two main categories:

1. speech troubles: phonatory, or articulatory, they hinder the utterance of speech strictly speaking;

2. language troubles: they show themselves in the use of language as manipulation of linguistic signs.

Speech troubles occur at different levels as a consequence of the neuromotor troubles characteristic of cerebral palsy. They can be of phonatory nature (impossibility to form proper sounds in the oral cavity: *dyslalia*), and of articulatory nature (lack of control of the muscles which govern articulation: *dysarthria*).

Language troubles of the subjects possibly affect many linguistic competences. They are symptomatically similar to those observed for dysphasic subjects. We may distinguish:

1. Semantic troubles

They often affect the emergence of abstract concepts and categories. Some subjects are unable to group into a single concept several instances of a category. Some may form improper categories, for example confuse concepts belonging to the same semantic domain.

More scarcely, one may observe, like in adult aphasia, troubles of lexical access: missing word or jargon.

2. Syntactic troubles

Most widespread, they appear in the subjects' communication as a more or less flagrant destructure of the utterances. The children reach a stage in the development of syntactic competence and cannot progress beyond that stage. This implies weak grammaticality, and frequently goes along with subjects' preference to short utterances. Furthermore, two noticeable trends have emerged from corpus analysis:

First, no, or very few, morphosyntactic information is inserted in the message: absent or improper flexion, no "grammatical words". For example, coordination is seldom explicitly conveyed by a particle, neither are semantic relations like attribution, property ... The subjects tend to use only "meaningful" words, producing telegraphic-style utterances.

Second, the order of the words or symbols in the utterances is not systematically determined by regular rules of grammatical nature. It is chiefly guided by the focus of the message, leading to topicalized utterances. Concepts do not go through a linear encoding of a deep syntactic structure.

These observations led us to consider semantic analysis as the appropriate way to get the meaning of these utterances.

There are different symptom clusters in situations of dysphasia; but the two main and most widespread symptoms are phonological (speech) and syntactical (language) disorders. This study has been led with a purpose of pragmatic communication aid, more than in a speech therapy perspective. Hence we will focus on the syntactical disorders and the methods proposed to make up for them.

2.3 Adaptative and Augmentative Communication

To make up for those difficulties in using language, rehabilitation centers use a set of vicarious symbolic systems generically referred to as AAC (*Adaptative and Augmentative Communication*) [7].

Several artificial languages have been developed for educational, rehabilitation or communication purposes. These languages are grounded on the preserved linguistic capabilities, which mainly consist in loose categorization and semantic association. They do not rely on any rigid structure, as syntax is beyond the reach of the language impaired patients. These languages are symbolic or iconic and include Bliss, Communimage and Grach.

1. The Bliss pictographic alphabet [1] is composed of ideograms which can be assembled with atomic ideographic elements. It is the most elaborate of the three, and may represent some abstract notions.
2. The Communimage icon set is composed of highly representative figurative drawings.
3. The GRACH symbol set is also of an iconic nature, although more stylized than the Communimage.

Those languages offer:

1. an easier access to meaning, as many of these systems use figurative icons. Even the Bliss alphabet is based on a non-arbitrary relation between a symbol and its signified concept;
2. correlated to the previous point, a more limited set of symbols, excluding in particular subtleties for abstract notions, and excluding “empty”, i.e. grammatical words;
3. absence of a specified syntax, the iconic or pictographic language offering simply a set of isolated symbolic conventions with very few dialectal pressure (i.e. collectively set habits of using them).

The discourse that these symbolic systems allow the subjects to produce is thus essentially based on semantics.

The utterances have an underlying semantic structure representing their meaning, where the semantic units are linked to the others through causal relations. This meaning is expressed by the mere sequence of symbols corresponding to the semantic units, as there is no way to express the type of causal relations. There is a directionality in the semantic structure which is expressed by the order of the symbols in the sequence.

While these iconic languages can be interpreted by medical staff, the process of automating their interpretation through computer appears to have several benefits, including giving a correct feedback on patients (which can serve rehabilitation purposes) and enabling them to communicate with a broader environment, not restricted to their family and medical staff. Because these language have a finite set of semantic contents, automatic processing also appears feasible.

3 Semantic Analysis

Therapists or parents of language impaired children generally understand the children's messages because they reconstruct the global meaning by attributing

a correct semantic role to every word or symbol. We tried to formalize this process so as to be able to implement it in a communication help software.

The first step is to ground our work material on the phenomena observed in the corpus. We collected a corpus reflecting the spontaneous use of symbolic languages (mainly Bliss and Communimage) by language-impaired children. This corpus is a set of icon sequences (average length of four) which constitute single “utterances”, each one being usually interpreted by a Bliss-skilled nurse. Examples of utterances in the corpus are: I/PUT/FLOWER/TABLE, I/WANT/SLEEP, I/WANT/EAT/FISH/CAKE, ANIMAL/PLAY/BALL ...

Study of the corpus led to consider two main semiotical facts:

1. paradigmatic structures: some sets of icons obviously form semantic categories, as they may appear in the same contexts (e.g. the category of “meals”, which all come with the pictogram for “eating”);
2. syntagmatic structures: some icons very systematically appear along with some complemental icons, within the same sequence, which belong to regularly the same categories (typically the pictogram “to eat” with an icon representing an animal or human being, and with another icon representing a meal). *Syntagmatic* structures don’t mean *syntactic* structures, as no compulsory order is always respected, but they form “frames” which represent the basic context associated to a particular icon.

These facts were to support a representation of the iconic language which is exposed below:

3.1 Cognitive and Linguistic Postulates

The language we are trying to analyse has the following two main characteristics:

1. It is generated from a lexicon of invariant, meaningful words or symbols. Following linguistic evidence [8], we organized the lexicon into *ad hoc* categories arising from corpus studies, *taxemes*. These taxemes are groups of symbols which have a common semantic base and may be used in the same contexts, e.g. the taxeme of beverages. Every taxeme is part of a *semantic domain*. The domains give a frame for general semantic consistency of the utterances.

The semantic content of a terminal in the lexicon is thus composed of:

- (a) a semantic domain;
- (b) a semantic category: the taxeme;
- (c) some specific semantic content distinguishing it from the other members of the same taxeme.

2. The utterances of the language are short sequences with no formal structure where the main semantic units are disposed in a topicalized order.

They have an underlying semantic structure representing their meaning, where the semantic units are linked to the others through causal relations. This meaning is expressed by the mere sequence of symbols corresponding to

the semantic units, as there is no way to express the type of causal relations. There is a directionality in the semantic structure which is expressed by the order of the symbols in the sequence.

It could be argued whether these postulates on the nature of the language of dysphasic subjects are not oversimplifications of complex disorders of the manipulation of syntactic structures. However we have adopted them as a good approximation for short sequences of symbols.

Having thus pointed out the properties of the subjects' language, postulated out of corpus evidence, we may define a model fit for implementation.

3.2 Formalization

In order to manipulate the semantic content of the symbols, we use a structural description based on semantic features. Every symbol has generic features inherited from the domain and the taxeme it belongs to, and specific features identifying it inside the taxeme.

A feature is defined as a simple attribute-value couple, where the value is always an atom. In most cases in our lexicon, the elementary features we use have a binary value: +1 or -1.

The number of features used to define the content of one symbol is not set a priori, but depends on the needs to distinguish it from other symbols. This approach, which is the approach of *differential semantics* [8], is based on the corpus only, and ensures compatibility with assessed semiotic phenomena. It has the drawback of setting combinatory problems when the size of the lexicon grows, but we have been dealing up to now with a small corpus and have not met the problem yet.

The meaning content of an utterance is represented by a network in which the vortices are semantic units and typed arcs are causal relations, like in Fig. 1. Topicality is represented by an order defined on the vortices of the network.

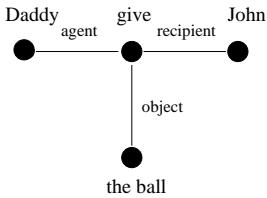


Fig. 1. The semantic network

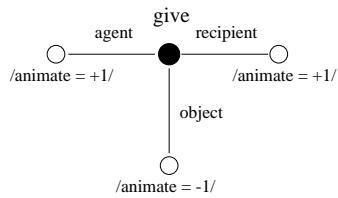


Fig. 2. A potential causal structure

The basic operation chosen to represent dynamic manipulation of semantic data is *unification* [6]. A semantic relation in a network is the actualization of a potential structure where some variables are left uninstantiated. These potential structures are typical causal structures, observable in the corpus, which are "fossilized" in the lexicon (like in Fig. 2). The semantic information borne by these structures is represented as selectional features, which condition the unification of a symbol as the causal filler of another.

3.3 Heuristics for Automatic Understanding

Natural Language Understanding systems are classically based on a first step being the parsing of formal structures. [2] defines a dependency parser for free word order languages such as latin, but it still relies on syntactic (to be exact, morphological) information.

Our aim in this study is to provide a good analysis of a language which has a limited expressive power, but provides no syntactic information to guide understanding. As we have postulated (3.1.2.) that this language is flatly generated from a semantic network where the organization is provided by semantic relations, we shall logically extract information from the sequences by trying to identify these semantic relations, in order to find back a semantic network.

This is done by trying to match the best case fillers to every potential causal structure attached to a symbol in the sequence.

The input to analyse is a sequence of symbols s_1, s_2, \dots, s_n , where every symbol in the sequence has a set of intrinsic features defining its semantic content: $\mathcal{IF}(s_i) = F$ (F is a set of semantic features).

Some symbols in the sequence are “predicative” symbols, i.e. a potential causal structure may be attached to them. The causal structure is a set of causal relations, each of which has a set of selectional features attached to it:

$$\mathcal{CS}(s_i) = \{< c_1, F_1 >, < c_2, F_2 >, \dots, < c_k, F_k >\}$$

(where c_j is the type of a causal relation, and F_j is a set of semantic features).

We note the set of selectional features attached to the (predicative) symbol s_i for the case c_j : $\mathcal{SF}(s_i, c_j) = F$ (which is equivalent to $< c_j, F > \in \mathcal{CS}(s_i)$).

We define the “value” of a case-filling unification, i.e. the value of the symbol s_k as a filler for the case c_j of the predicative symbol s_i , as the *semantic compatibility* of the intrinsic features of s_k to the selectional features of s_i for the case c_j :

$$\mathcal{V}(s_i, c_j, s_k) = \mathcal{C}(\mathcal{SF}(s_i, c_j), \mathcal{IF}(s_k)) \quad (1)$$

The relation of semantic compatibility of a set of semantic features to another is itself defined as:

$$\mathcal{C}(F_1, F_2) = \frac{\sum_{f_i \in F_1 \cap F_2} \mathcal{X}(f_i, F_1, F_2)}{\text{number of elements in } F_2} \quad (2)$$

where $\mathcal{X}(f_i, F_1, F_2) = +1$ if f_i has the same value in F_1 as in F_2 ,
 $= -1$ otherwise.

This relation is asymmetric: it measures the degree of fitness of the set F_2 to the set F_1 .

An *affectation A* of a set of candidate symbols $S = \{s_{i1}, s_{i2}, \dots, s_{ij}\}$ as case-fillers to the predicative symbol s_i is an application of the set of cases of s_i ($\mathcal{CS}(s_i) = \{< c_1, F_1 >, < c_2, F_2 >, \dots, < c_k, F_k >\}$) into the set of candidate symbols:

$$A = \{< c_x, s_{iy} >\}, \text{ where } x \in [1, k] \text{ and } y \in [1, j]. \quad (3)$$

We define the global value of an affectation A of the symbols $s_{i1}, s_{i2}, \dots s_{ik}$ as case-fillers of the predicative symbol s_i as the sum of the values of every single unification:

$$\mathcal{V}(s_i, \{< c_1, s_{i1} >, < c_2, s_{i2} >, \dots < c_k, s_{ik} >\}) = \sum_{j \in [1, k]} \mathcal{V}(s_i, c_j, s_{ij}) \quad (4)$$

Hence, the search of a best interpretation of the sequence is the search, for every predicative symbol of the sequence, of the best affectation of other symbols as its case-fillers, i.e. the search of a maximum for the value defined above:

$$\max_A \mathcal{V}(s_i, A) \quad (5)$$

3.4 Implementation

Sample PROLOG code is provided to illustrate the implementation.

Intrinsic features of the symbols are defined in the internal database:

```
feature(Sym, (Att, Val)).
```

So are the predicative symbols' selectional features, attached to their causal relations:

```
case(Sym, Cas, (Att, Val)).
```

The semantic compatibility of a set of semantic features to another is calculated based on the number of selectional features satisfied by the presence of the corresponding intrinsic features (with the same value):

```
compatible_ratio(L, [], (0, Den)) :-  
    length(L, Den).  
  
compatible_ratio(L1, [(Att, Val) | L2], (Sum, Den)) :-  
    member((Att, Val), L1), !,  
    compatible_ratio(L1, L2, (Psum, Den)),  
    Sum is Psum+1.  
  
compatible_ratio(L1, [(Att, Val2) | L2], (Sum, Den)) :-  
    member((Att, Val1), L1), !,  
    Val1 =\= Val2,  
    compatible_ratio(L1, L2, (Psum, Den)),  
    Sum is Psum-1.  
  
compatible_ratio(L1, [(_ , _) | L2], (Sum, Den)) :-  
    compatible_ratio(L1, L2, (Sum, Den)).
```

```
compatible_float(L1,L2,Real) :-  
    compatible_ratio(L1,L2,(Sum,Den)),  
    Real is Sum/Den.
```

The semantic value of an affectation is the sum of the semantic values of every single unification of a symbol to a case:

```
affectation(Pred, [], _, 0).
```

```
affectation(Pred, [Cas|Lc], [Sym|Ls], Score) :-  
    bagof((SelAtt,SelVal),  
        case(Pred,Cas,(SelAtt,SelVal)),  
        LselFeat),  
    bagof((IntAtt,IntVal),  
        feature(Sym,(IntAtt,IntVal)),  
        LintFeat),  
    compatible_float(LselFeat, LintFeat, UnifScore),  
    affectation(Pred,Lc,Ls,Pscore),  
    Score is Pscore+UnifScore.
```

The search of the best affectations is then the result of a *quick sort* algorithm.

3.5 Other Elements of the Analysis Process

With the analysis technique described in 3.3, there potentially could be a correct interpretation of any sequence of symbols, provided that the total number of causal relations in the causal structures reaches the number of symbols in the sequence minus one. As a matter of fact the search for a maximum always yields a result, even if the maximum is negative.

Pragmatically, this is unrealistic and might lead to utter nonsense. The data given in the corpus show that a minimal isosemy is present in any utterance, guaranteeing its consistency.

We have thus introduced a first constant, the *acceptability threshold*. Individual semantic unifications whose values do not exceed this threshold are rejected.

Similarly, the topicality of the utterances makes it unlikely that long distance semantic attachments exist between two symbols which are not in a close vicinity in the sequence. This locality constraint becomes relevant as soon as sequences are 4 or 5 symbols long. To take it into account, we have defined a second constant, the *locality* constant, which represents the fading of semantic relations with the linear distance in the uttered sequences.

Practically, this constant will intervene in the calculus of the value of a semantic unification at the power of n , n being the distance between the two semantic units within the sequence.

This constant is a rough way of modeling the effect of distance in semantic relations inside a text (in a broad sense). We use it successfully on our small examples.

Both the acceptation threshold and the locality constant have been defined by iterative tries based on the corpus.

4 The Application

The technique of semantic analysis described above has been implemented in an adaptative and augmentative communication application: PVI (*Prothèse Vocale Intelligente*, i.e. Intelligent Voice Prosthesis), available as a software program for portable computers. This application has a broader scope which also includes assisting the subjects for pictogram input, taking into account their motor disabilities, as well as generating correct sentences in natural language (French) from the semantic networks obtained after the analysis.

As the differential semantic description appears to be common both to symbolic languages and natural language, it provides the basis for conversion of one language into another. To convert a semantic representation into natural language assumes that the process of semantic analysis can be somehow reversed, a processing phase called lexical choice. It consists in determining which words can be formed from the network of semantic features yielded by the semantic analysis. This is mainly a matter of reorganizing the semantic content into relevance islands. These islands are determined by the proper description of an object or an action. For instance, every feature describing the same object will be grouped into a single word - if such a word exists - no matter which icon they come from. This is performed through a natural language dictionary described with the same semantic features as the icon vocabulary, and a set of heuristics.

Of course, in natural language, even simple utterances have to follow syntactic well-formedness principles. This is why conversion between symbolic and natural language cannot rely purely on semantic knowledge but has to include syntactic information in the late stage of translation. Syntactic information is incorporated into syntactic trees in the formalism of Tree-Adjoining Grammar [5]. This accounts for a predicate-centered syntactic representation accepting various modifiers which fit the basic phenomena encountered. More complex syntactic phenomena such as long-distance dependencies fall out of our scope.

As a whole, the PVI application should be a completely transparent application with a customizable, graphical front-end for the user, and a natural language front-end for the interlocutors, ideally acting as a filter between agrammatical pictographic designation and natural language.

Sample utterances treated by the application:

```
?- transfer([i,eat,meat],Sentence).
Sentence = "Je mange la viande"                                "I eat the meat"
?- transfer([meat,i,eat],Sentence).
Sentence = "Je mange la viande"                                "I eat the meat"
?- transfer([fork,i,eat],Sentence).
Sentence = "Je mange avec la fourchette"                      "I eat with the fork"
?- transfer([fork,i,eat,meat],Sentence).
Sentence = "Je mange la viande
avec la fourchette"                                         "I eat the meat with the fork"
?- transfer([i,give,cat,meat],Sentence).
Sentence = "Je donne la viande au chat"                         "I give the meat to the cat"
```

```
?- transfer([i,give,cat,daddy],Sentence).
Sentence = "Je donne le chat Papa"           "I give the cat to Daddy"
```

5 Evaluation

The system has been submitted to a benchmarking test: a set of 200 icon sequences, reproducing in their structure a number of spontaneously uttered patterns, has been given as input for content analysis and language generation.

The results were indexed into the four following categories, depending on their correct analysis but also on the “naturalness” of the French sentence produced: (I) Correct analysis, correct generation; (II) Correct analysis, clumsy generation; (III) Incomplete or clumsy analysis; (IV) Incorrect analysis.

The results were the following: category I: 147 sequences; category II: 15 sequences; category III: 15 sequences; category IV: 18 sequences.

When we decide to consider “acceptable” the sequences which were either correctly analysed and generated, or correctly analysed but imperfectly generated (and still comprehensible), that is when we merge categories I and II, we thus get an acceptability rate of 80.5 % on this benchmark.

This of course must not be taken for a global acceptability level of the PVI system by the user in an ecological situation. During on-site evaluation, which was conducted during five months with six individuals subject to cerebral palsy in the rehabilitation center of Kerpape (Brittany, France), a certain number of problems linked to real-life situations were unveiled:

1. unexpected answers from the system, even if they are a minority, very soon get the user frustrated and nervous, since the actual input of the sequence of icons by a person suffering from motor disabilities is rather long (it may be counted in minutes). A bad result is thus immediately resented as a frustrating waste of time;
2. lack of vocabulary can not easily be overridden by hand gestures or segments of words, as it is the case during direct communication — or else the missing element in the sequence will lead to nonsense. We have been asked with emphasis to increase the initial vocabulary of the system (grossly 300 icons) whose limits are reached very soon;
3. problems of interface ergonomics are sometimes crucially important for users who have only a few interface points with the system.

However, these critiques might be interpreted as an encouragement to develop a promising prototype, whose principles have been validated, and to adapt it to the realities of difficult ecological situations.

6 Conclusion

We have proposed and implemented a semantic analyser which performs manipulation of symbolic knowledge. It has proved to be successful in the interpretation of weakly structured utterances of symbols.

Further reflexion will aim at taking into account other semantic phenomena. Very interesting ones are contextual meaning effects, which should be described by *dynamic* manipulation of semantic features.

Another arising topic of interest is the more detailed theoretical study of how visual (icon or pictogram) semantics and language semantics intersect and interact with each other.

The technique exposed in this paper was designed to cope with a specific problem of language alteration for dysphasic subjects, but its availability might open new perspectives. Language prostheses have a great potential for the rehabilitation of language impaired patients. In particular, its adaptation to adult traumatic aphasia, with the experience in the field of rehabilitation for these cases, might bring promising results.

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